Conf-910435--71

CONF-910435--71

DE91 011941

MAJOR RESULTS OF GRAVITY AND MAGNETIC STUDIES AT YUCCA MOUNTAIN, NEVADA

H.W. Oliver, D.A. Ponce, and R.F. Sikora
U.S. Geological Survey
345 Middlefield Road
Menlo Park, California 94025

ABSTRACT

About 4,000 gravity stations have been obtained at Yucca Mountain and vicinity since the beginning of radioactive-waste studies there in 1978. These data have been integrated with data from about 29,000 stations previously obtained in the surrounding region to produce a series of Bouguer and isostatic-residual-gravity maps of the Nevada Test Site and southeastern Nevada. Yucca Mountain is characterized by a WNW-dipping gravity gradient whereby residual values of -10 mGal along the east edge of Yucca Mountain decrease to about -38 mGal over Crater Flat. Using these gravity data, two-dimensional modeling predicted the depth to pre-Cenozoic rocks near the proposed repository to be about 1,220±150 m, an estimate that was subsequently confirmed by drilling to be 1,244 m. Three-dimensional modeling of the gravity low over Crater Flat indicates the thickness of Cenozoic volcanic rocks and alluvial cover to be about 3,000 m. Gravity interpretations also identified the Silent Canyon caldera before geologic mapping of Pahute Mesa and provided an estimate of the thickness of the volcanic section there of nearly 5 km.

Considerable aeromagnetic coverage of southwestern Nevada was obtained in 1978-79 to help characterize Yucca Mountain and vicinity. One significant result is the discovery of a series of circular magnetic anomalies in Crater Flat and the northern Amargosa Desert that suggest the presence of buried volcanic centers there. If this interpretation is confirmed by drilling, the magnetic data can be used to help estimate the total volume of buried volcanic rocks, which, along with radiometric dating, could help provide a better prediction of future volcanism. Elongate magnetic highs and associated lows over Yucca Mountain correlate with mapped faults, some of which are only partially exposed. Thus, the data provide information on the extent and continuity of these faults.

On a regional scale, analysis of magnetic data from southwestern Nevada has produced estimates of the depth to the Curie-temperature isotherm. A depth in southwestern Nevada of about 15 km increases northward to about 30 km east of Tonopah within the general area defined as the Eureka heat flow low.

INTRODUCTION

Gravity and magnetic investigations of Yucca Mountain and vicinity began in 1978 to help characterize the general geologic and tectonic setting of a potential site for the disposal of high-level radioactive waste. At that time, only a few gravity stations and no aeromagnetic data were available for Yucca Mountain, although extensive geophysical measurements had been made for about 20 years in the northern and eastern parts of the Nevada Test Site (NTS) in connection with nuclear testing. By 1984, about 3,000 new gravity stations had been obtained within 100 km of Yucca Mountain, much of the area flown for aeromagnetic measurements, and a report issued summarizing preliminary results.[1] By 1987, when Yucca Mountain was chosen for detailed characterization over other sites in Washington and Texas[2,3] by the U.S. Congress, another 1,000 regional gravity stations had been obtained. However, fieldwork was curtailed abrubtly in April 1988 because of the need to develop a quality assurance program to support possible licensing procedures. Interpretation of existing data and preparation of technical reports are continuing, and several new geophysical maps have recently been compiled.

Gravity studies are particularly useful to (1) characterize the general configuration of pre-Cenozoic basement, (2) detect concealed or unrecognized faults, (3) estimate the offset or extent of known faults, and (4) detect and characterize such igneous features as calderas and buried plutons. Gravity methods can detect shallow as well as deep features that juxtapose rocks of significantly different densities. With appropriate horizontal and

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, make any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

vertical controls, gravity data can also reveal undulations of the base of the crust, which occur at a depth of approximately 33 km beneath Yucca Mountain, on the basis of seismic-refraction data.

Very few aeromagnetic data and no ground magnetic data in the southwestern part of the NTS were available in 1978. In 1979-80, aeromagnetic surveys were flown over the Yucca Mountain area, the Timber Mountain area, and the Spring Mountains south of the NTS. Magnetic data from these areas have proved most useful for (1) determining which areas of buried basement are magnetic, as a clue to composition, and (2) locating buried volcanic centers and concealed faults.

GRAVITY DATA AND MAPS

The 4,000 new gravity measurements have been combined with about 29,000 previous measurements made within a distance of 100 km of Yucca Mountain to produce Bouguer and isostatic-gravity maps of the region.[1,4,5,6] The accuracies of the gravity measurements are generally 0.05 mGal, but gravity anomalies derived from these measurements are less accurate, particularly in mountainous terrain. Anomalies calculated from the gravity data generally have an uncertainty of about 0.3 mGal, although the relative accuracy of detailed profiles may be less than about 0.1 mGal. Regional gravity anomalies generally range from 5 to 50 mGal in amplitude, but the gravity effects of concealed faults may be less than 1 mGal, thus requiring more detailed measurements. Gravity maps and profiles based on these data have been compiled for several areas at various scales, and the principal facts have been released on magnetic tape.[7,8]

Fig. 1 shows the topography of the NTS and vicinity and, in particular, the location of the proposed radioactive-waste repository (PR, Fig. 1) on the east side of Yucca Mountain, just west of the southwest boundary of the NTS. Fig. 2 shows the variation in isostatic residual gravity in the same area as Fig. 1, from a high of about +14 mGal over Bare Mountain in the southwest corner of the map area to a low of about -65 mGal over Pahute Mesa in the northwestern part of the NTS. Gravity lows of about -28 and -34 mGal occur over Yucca Flat (YF, Fig. 2) and Frenchman Flat (FF, Fig. 2), respectively. Yucca Mountain (Fig. 2) is characterized by a northwest-dipping gravity gradient whereby gravity values of about -10 mGal over the east edge of Yucca Mountain decrease to about -38 mGal over Crater Flat. A larger-scale gravity map of this area with 2-mGal contours is also available.[9]

ROCK DENSITIES

Rocks in the NTS and vicinity can be separated into three major groups on the basis of density: pre-Cenozoic sedimentary rocks, and intrusive rocks with an average density of about 2.67 g/cm^3; Cenozoic volcanic rocks, with a density of about 2.4 g/cm^3; and nonwelded and partially welded ash-flow tuffs and alluvium, with a density of about 2.0 g/cm^3.[11] Rock-density information on the NTS and vicinity has been obtained from rock samples (including core samples), borehole gravity meter surveys, and borehole density logs (gamma-gamma).

GRAVITY RESULTS

Many regional subsurface geologic features in the NTS and vicinity were initially identified from the gravity data. One major result was a prediction of the depth to pre-Cenozoic basement rocks at proposed drillhole UE-25p#1, just southeast of the proposed repository (DH, Fig. 1). On the basis of two-dimensional gravity modeling of the gravity gradient across Yucca Mountain and extension of profiles to outcrops of Paleozoic basement rocks on either side, H.W. Oliver and D.L. Healey (written commun., 1983) estimated the depth to basement to be about 1,220±150 m (4,000±500 ft) at the proposed drillhole. Subsequent drilling penetrated 1,244 m (4,080 ft) of Tertiary volcanic rocks overlying pre-Cenozoic dolomitic basement.[10] Additional three-dimensional gravity modeling[11] suggests that pre-Cenozoic basement increases in depth westward directly under the proposed repository (PR, Fig. 1) and reaches about 3,000 m (10,000 ft) under Crater Flat.[11] This basement model is consistent with recent seismic-refraction data (W.D. Mooney and S.C. Schapper, written commun., 1989) but has not yet been confirmed by drilling. Drill hole UE-25p#1 is the only hole in the Yucca Mountain area to reach pre-Cenozoic basement. The deepest drill holes in the Yucca Mountain-Crater Flat area other than UE-25p#1 are about 1,800 m (6,000 ft) deep and bottom in Miocene volcanic rocks.

Gravity interpretations also identified the Silent Canyon caldera underlying Pahute Mesa on the northern part of the NTS (Fig. 1), where modeling of a -65-mGal gravity low indicates a volcanic section at least 4,830 m (16,000 ft) thick.[12] — Drilling to 4,173 m (13,686 ft) within the gravity anomaly, as well as surface mapping,[13] has since confirmed the gravity model. Similarly, interpreted gravity data from the Timber Mountain (TM, Fig. 2) area determined that (1) a broad gravity high over the southeast side of Timber Mountain is associated with exposed Miocene

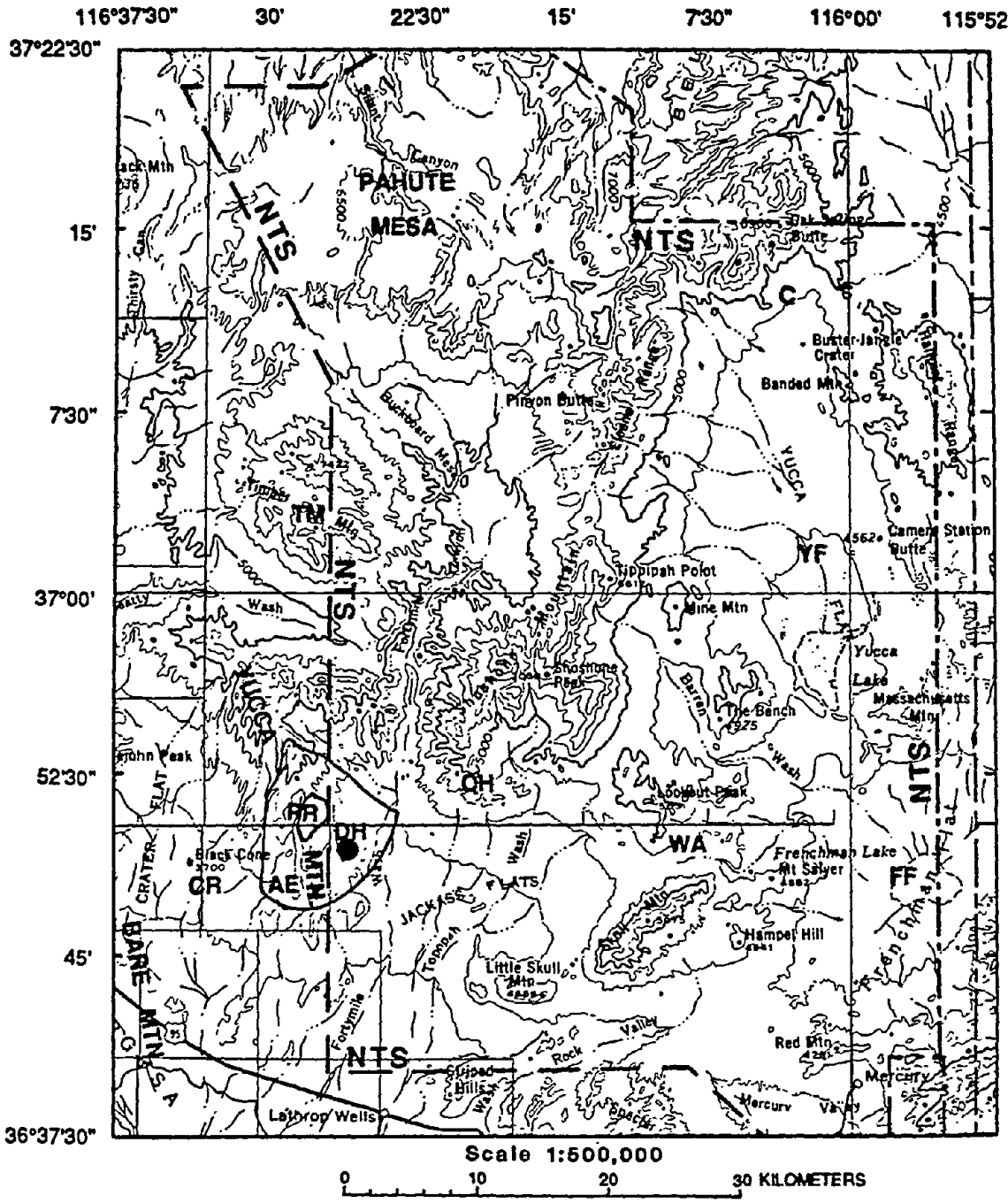

Figure 1 Topographic map of the Nevada Test Site (NTS) and vicinity showing place names referred to in the text. AE, Boundary of assessible environment; C, Climax Stock; CH, Calico Hills; CR, Crater Flat; DH, Drill Hole UE-25p#1; FF, Frenchman Flat; PR, Proposed repository; TM, Timber Mountain; WA, Wahmonie; YF, Yucca Flat.

intrusive rocks, which are denser than adjacent volcanic rocks, and suggests that this part of the caldera is underlain by such rocks;[14] and (2) the Timber Mountain caldera truncates the south edge of the older Silent Canyon caldera.[14]

Initial absolute and high-precision measurements were recently made in the vicinity of Yucca Mountain for calibration purposes and to detect possible future gravity changes.[15,16] Future remeasurements should be able to detect absolute changes in elevation of less than 5 cm or changes in subsurface structures, such as those revealed with gravity methods after the 1971 San Fernando, Calif., earthquake.[17]

Gravity surveys are useful to inexpensively study tectonic structures, particularly those that offset or cause variations in the depth to basement. The interpretation of gravity data alone, however, does not produce unique models of the subsurface. Therefore, closely spaced gravity data must be collected along traverses where other geophysical measurements, including seismic reflection and refraction, magnetic, and geoelectric, have been obtained. Also, density data must be obtained from surface measurements, gamma-gamma logs, and gravity meter borehole measurements to constrain gravity models.

MAGNETIC MEASUREMENTS AND MAPS

Aeromagnetic, ground magnetic, and magnetic property measurements have been made at the NTS and vicinity, Nev., in support of subsurface structural studies, Curie-temperature isotherm analyses, and correlation of volcanic strata. These data are also needed to locate and estimate the volume of buried Quaternary basalt for determining the probability of future eruptions and to locate concealed faults that offset strata within Yucca Mountain.[18,19]

Much of the present aeromagnetic coverage to a distance of about 15 km from Yucca Mountain consists of flightlines flown at a constant elevation above terrain, with spacings of 400 m (1/4 mi) and 800 m (1/2 mi); an area 5 km to the northwest was flown at a constant elevation above sea level. The draped data are generally 120 m (400 ft) above the ground surface whereas the barometric data were flown at a constant elevation of 2,440 m (8,000 ft) and so are much less detailed because the average elevation of the terrain is about 1,220 m (4,000 ft). The Death Valley area, about 50 km southwest of Yucca Mountain, was surveyed along flightlines at 120 m (400 ft) above ground and spaced 1.6 km apart. This survey was intended for reconnaissance exploration of uranium under the National Uranium Resource Evaluation (NURE) program. The flightlines, however, are too far apart and too low to detect many intervening shallow magnetic features; this coverage probably missed about a third of the buried magnetic structures. Thus, the NURE data are regarded as inadequate for detailed structural studies, and the Death Valley area needs to be reflown with a more consistent line spacing and drape height above terrain, such as 400-m spacing at 200 m above terrain.

Regional aeromagnetic data have been compiled at a scale of 1:2,500,000 by mathematical continuation of all data sets to a common surface of 3,800 m (12,500 ft) above sea level.[20] A larger-scale regional aeromagnetic map was also prepared by continuing these data either downward or upward to a height of 305 m (1,000 ft) above terrain at a scale of 1:750,000.[21] A 20-nT-contour aeromagnetic map of Yucca Mountain and vicinity is available at 1:48,000,[22] as well as a detailed index and listing of all aeromagnetic surveys in southern Nevada.[23,24]

An aeromagnetic map of the NTS and vicinity is shown in Fig. 3, covering the same area as Fig. 1. Yucca Mountain (YM, Fig. 3) is characterized by several N-S-elongate magnetic lows and highs, with local amplitudes of about 100 nT. To the west over Crater Flat (CF, Fig. 3), a magnetic high of about 200 nT is flanked on the southwest by several lows of about 200 nT. The north third of Yucca Mountain is traversed by a WNW-trending magnetic high of several hundred nanoteslas that extends from Wahmonie (W, Fig. 3) to the west edge of the map area near lat 37° N. The largest magnetic feature within the NTS is the approximately 500-nT positive anomaly near the Climax Stock (C, Fig. 3) in the northeastern part of the area. Several northwest-trending magnetic highs and lows are located over Timber Mountain and Pahute Mesa. A larger-scale (1:100,000) magnetic map of the area shown in Fig. 3 has recently been compiled.[25]

MAGNETIC RESULTS

One of the most important results from magnetic studies is the discovery of several magnetic anomalies over alluvial areas in Crater Flat and the Amargosa Desert just west and south of Yucca Mountain. These magnetic anomalies are similar to those associated with exposed Quaternary volcanic centers and basalt flows. If this correlation is confirmed by planned drilling, the magnetic data could be used in combination with other methods and drilling to estimate the total volume of buried volcanic rocks that must be considered in evaluating the probability for future eruptions which could affect repository performance.[22,26,27]

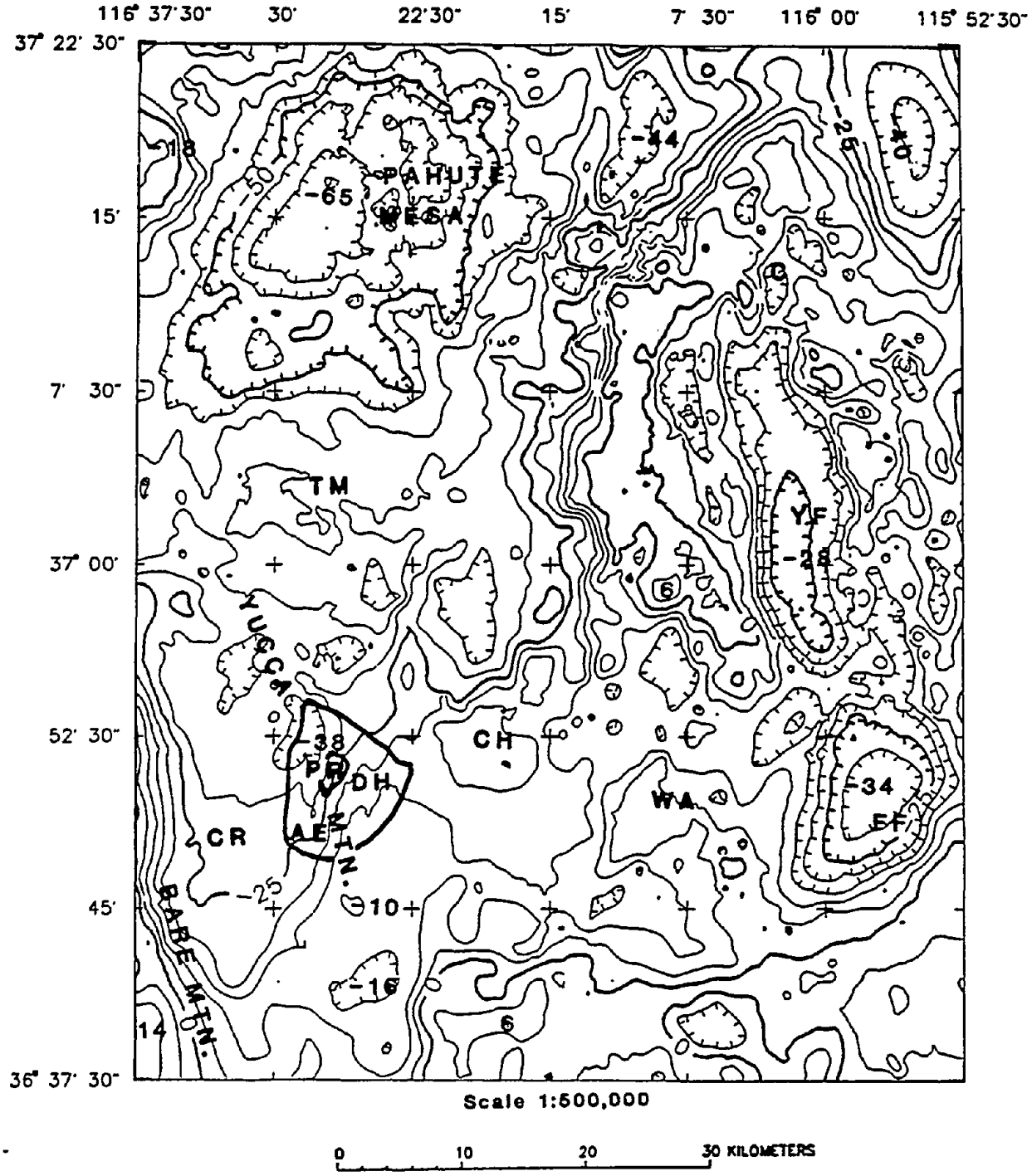

Figure 2 Isostatic gravity map of Yucca Mountain and vicinity reduced for a density of 2.67 g/cm^3, a sea-level crustal thickness of 25 km and a crust-mantle density contrast of 0.4 g/cm^3. Contour interval 5 mGal[7]. Abbreviations on map are the same as in Figure 1. Hachures indicate closed lows.

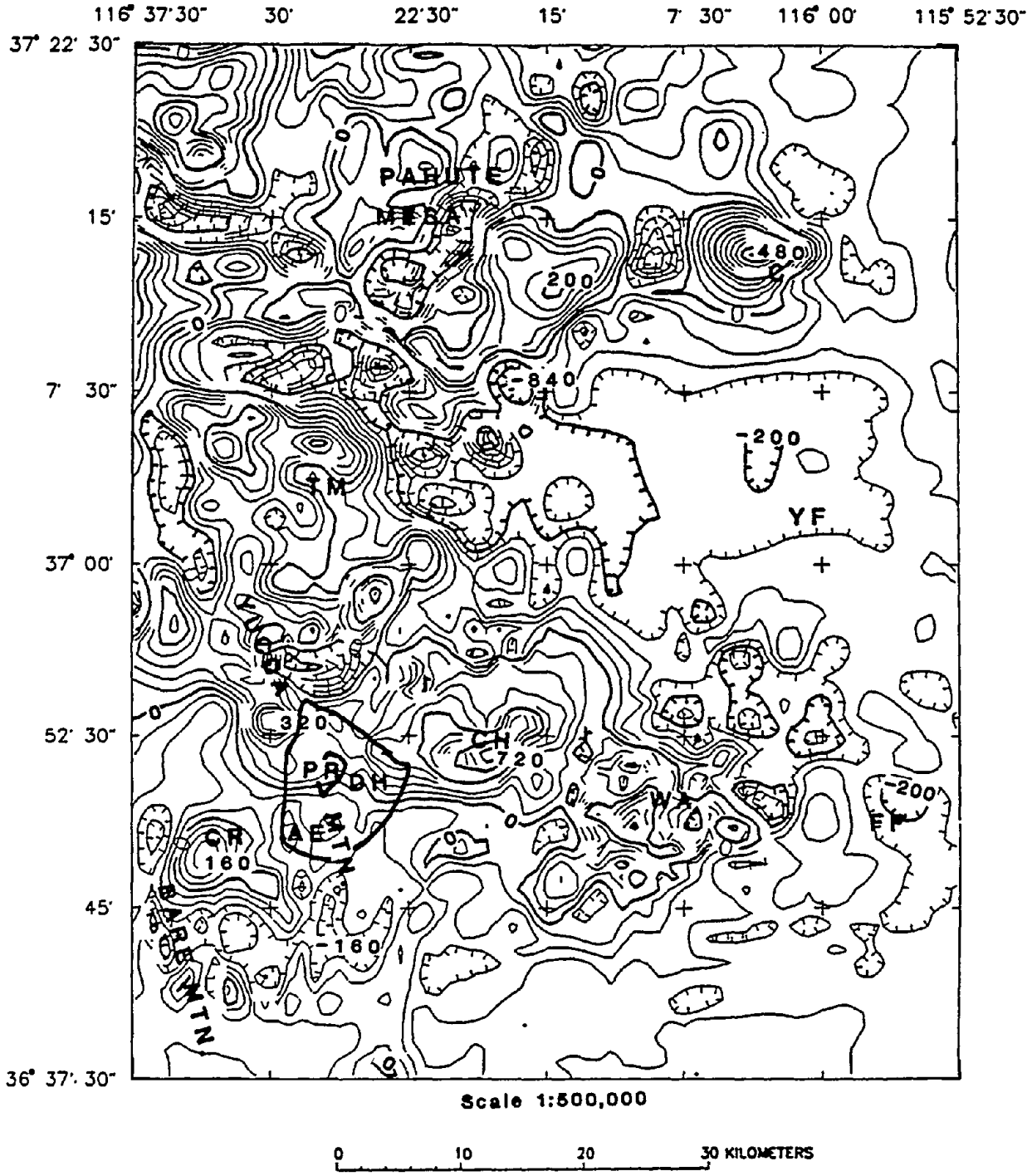

Figure 3 Aeromagnetic map of Yucca Mountain and vicinity at 300 m (1,000 ft) above ground. Contour interval 40 nT. Abbreviations on map are the same as in Figure 1. Hachures indicate closed lows.

Another significant finding is the presence of a WNW-trending magnetic high over northern Yucca Mountain, extending eastward to Wahmonie (Fig. 3). At the Calico Hills (CH, Fig. 1) just east of Yucca Mountain, this regional high is known from drilling to be associated with magnetite-bearing, thermally altered, argillaceous basement rocks of the Pennsylvanian Eleana Formation.[1,29] Farther east at Wahmonie (WA, Figs. 1 and 3), however, the high occurs over Miocene felsic intrusive rocks. Thus, although the basement under northern Yucca Mountain is magnetic, its composition is uncertain; it is probably argillitic rather than dolomitic.

The above-mentioned gradients between elongate magnetic highs and associated lows over Yucca Mountain correlate with mapped faults, some of which are only partly exposed. The extent and continuity of such faults with depth concern the characterization of the proposed repository site at Yucca Mountain, and high-resolution magnetic surveys in combination with other geophysical methods may provide useful resolution of these features.

Analysis of the statistical properties of magnetic anomalies throughout Nevada has produced estimates of the depth within the Earth's crust to the Curie-temperature isotherm (a temperature of about 580°C, depending chiefly on the titanium content of magnetic minerals in the crust). Results of Curie-isotherm analysis indicate that the isotherm depth in southwestern Nevada is about 15 km and that it increases northward to about 30 km within the general area defined as the Eureka heat flow low near lat. 38° N., long. 116° W., east of Tonopah, Nev.[30,31]

AKNOWLEDGMENTS

Prepared in cooperation with the U.S. Department of Energy (interagency agreement DE-AI08-78ET44802).

REFERENCES

1. U.S. GEOLOGICAL SURVEY, A Summary of Geologic Studies through 1983 of a Potential High-level Radioactive Waste Disposal Site at Yucca Mounta, Southern Nye County, Nevada: U.S. Geological Survey Open-File Report 84-792, 103 p. text + 51 illus (1984).

2. OLIVER, H.W., Introduction to Specia Sections on geophysical investigations of proposed waste disposal sites: Journal of Geophysical Research, v. 92, no. B8, p. 7783-7785 (1987)

3. MANASTERSKY, RICHARD, The 10,000-year test: Science News, v. 133, no. 9, p. 139-141 (1988).

4. See Fig. 2.1-1 of H.W. OLIVER, E.L. HARDIN, and P.H. NELSON, eds., Status of Data, Major Results, and Plans for Geophysical Activities, Yucca Mountain Project: U.S. Department of Energy Report YMP/90-38, 231 p (1990).

5. R.W. SALTUS, Bouguer Gravity Anomaly Map of Nevada: Nevada Bureau of Mines and Geology Map 94A, scale 1:750,000 (1990).

6. R.W. SALTUS, Regional, Residual, and Derivative Gravity Maps of Nevada: Nevada Bureau of Mines and Geology Map 94B, scale 1:750,000 (1990).

7. R.W. SALTUS, Gravity Data for the State of Nevada on Magnetic Tape: U.S. Geological Survey Open-File Report 88-433, 20 p (1988).

8. R.N. HARRIS, D.A. PONCE, D.L. HEALEY, and H.W. OLIVER, Principal Facts for about 16,000 Gravity Stations in the Nevada Test Site and Vicinity: U.S. Geological Survey Open-File Report 89-682-A, Principal facts documentation, 78 p.; 89-682-B, Gravity data listing on paper, 227 p.; and 89-682-C, Gravity data on diskettes, 2 disks (1989).

9. D.A. PONCE, R.N. HARRIS, and H.W. OLIVER, Isostatic Gravity Map of the Nevada Test Site and Vicinity, Nevada: U.S. Geological Survey Open-File Report 88-664, scale 1:100,000 (1990).

10. M.D. CARR, S.J. WADDELL, G.S. VICK, J.M. STOCK, S.A. MONSEN, A.G. HARRIS, B.W. CORK, and F.M. BYERS, Geology of Drillhole UE25p#1: A Test Hole into Pre-Tertiary Rocks Near Yucca Mountain, Southern Nevada: U.S. Geological Survey Open-File Report 86-175, 87 p (1986).

11. D.B. SNYDER, and W.J. CARR, Interpretation of Gravity Data in a Complex Volcano-Tectonic Setting, Southwestern Nevada: Journal of Geophysical Research, vol. 89, no. B12, p. 10,193-10,206 (1984).

12. D.L. HEALEY, Application of Gravity Data to Geologic Problems at the Nevada Test Site, in Eckel, E.B. (ed.), Nevada Test Site: Geological Society of America Memoir 110, p. 147-156 (1968).

13. F.M. BYERS, JR., W.J. CARR, P.P. ORKILD, W.D. QUINLEVAN, and K.A. SARGENT, Volcanic Suites and Related Cauldrons of Timber Mountain-Oasis Valley Caldera Complex, Southern Nevada: U.S. Geological Survey Professional Paper 919, 70 p (1976).

14. M.F. KANE, M.W. WEBRING, and B.K. BHATTACHARYYA, A Preliminary Analysis of Gravity and Aeromagnetic Surveys of the Timber Mountain Area, Southern Nevada: U.S.

Geological Survey Open-File Report 81-189, 40 p (1981).

15. M.S. ZUMBERGE, R.N. HARRIS, H.W. OLIVER, G.S. SASAGAWA, and D.A. PONCE, Preliminary Results of Absolute and High-Precision Gravity Measurements at the Nevada Test Site and Vicinity, Nevada: U.S. Geological Survey Open-File Report 88-242, 29 p (1988).

16. R.N. HARRIS, and D.A. PONCE, High-Precision Gravity Network to Monitor Temporal Variations in Gravity Across Yucca Mountain, Nevada: U.S. Geological Survey Open-File Report 88-243, 19 p (1988).

17. H.W. OLIVER, S.L. ROBBINS, R.B. GRANNELL, R.W. ALEWINE, and S. BIEHLER, Surface and Subsurface Movements Determined by Remeasuring Gravity, in G.B. Oakshott (ed.), San Fernando Earthquake of February 9, 1971: California Division of Mines and Geology Bulletin 196, p. 195-211 (1975).

18. H.W. OLIVER, and D.A. PONCE, U.S. Geological Survey Scientific Investigation Plan - Geophysical Investigations, Gravity and Magnetic Methods: U.S. Geological Survey Administrative Report 3221G-01RO, 27 p. text + 5 illus (1987).

19. U.S. DEPARTMENT OF ENERGY, Site Characterization Plan, Yucca Mountain Site, Nevada Research and Development Area, Nevada: U.S. Department of Energy Report RW-0199, 9 volumes (1988).

20. T.G HILDENBRAND, A.M. ROGERS, H.W. OLIVER, S.C. HARMSEN, J.K. NAKATA, D.S. AITKEN, R.N. HARRIS, and M.D. CARR, Regional Geologic and Geophysical Maps of Southern Great Basin, in M.D. Carr and J.C. Yount (eds.), Geologic and Hydrologic Investigations of a Potential Nuclear Waste Disposal Site at Yucca Mountain, Southern Nevada: U.S. Geological Survey Bulletin 1790, p. 3-21 (1988).

21. T.G. HILDENBRAND, and R.P. KUCKS, Total Intensity magnetic Anomaly Map of Nevada: Nevada Bureau of Mines and Geology Map 93A, scale 1:750,000 (1988).

22. M.F. KANE, and R.E. BRACKEN, Aeromagnetic Map of Yucca Mountain and Surrounding Regions, Southwest Nevada: U.S. Geological Survey Open-File Report 83-616, scale 1:48,000, 19 p. text (1983).

23. J.W. ERWIN, S.L. NICHOLS, R.H. GODSON, and P.L. HILL, Aeromagnetic Map Index of Nevada: Nevada Bureau of Mines and Geology Map 62, scale 1:1,000,000 (1980).

24. P.L. HILL, Bibliography, Index, and Location Maps of Airborne Surveys In and West of the Rocky Mountain States: U.S. Geological Survey Open-File Report 86-525-A, 200 p (1986).

25. K.S. KIRCHOFF-STEIN, D.A. PONCE, and B.A. CHUCHEL, Preliminary Aeromagnetic Map of the Nevada Test Site and Vicinity: U.S. Geological Survey Open-File Report 89-446, scale 1:100,000 (1989).

26. B.M. CROWE, K.H. K.H. WOHLETZ, D.H. VANIMAN, E. GALDNEY, and N. BOWER, Status of Volcanic Hazard Studies for the Nevada Nuclear Waste Storage Investigations: Los Alamos National Laboratory Report LA-9325-MS, vol. 2 (1986).

27. V.E. LANGENHEIM, KIRCHOFF-STEIN, K.S., AND H.W. OLIVER, 1991, Magnetic investigations of buried volcanic centers near Yucca Mountain: U.S. Geological Survey Bulletin XXX, 14 p. (In press).

28. G.R. BOYNTON, J.L. MEUSCHKE, and J.L. VARGO, Aeromagnetic Map of the Timber Mountain Quadrangle and Part of the Silent Canyon Quadrangle, Nye County, Nevada: U.S. Geological Survey Geophysical Investigations Map GP-443, scale 1:62,500 (1963).

29. G.D. BATH, and C.E. JAHREN, Interpretation of Magnetic anomalies at a Potential Repository Site Located in the Yucca Mountain Area, Nevada Test Site: U.S. Geological Survey Open-File Report 84-120, 40 p (1984).

30. R.J. BLAKELY, Curie Temperature Isotherm Analysis and Tectonic Implications of Aeromagnetic Data from Nevada: Journal of Geophysical Research, vol. 93, no. B10, p. 11817-11832 (1988).

31. J.H. SASS, A.H. LACHENBRUCH, R.J. MONROE, G.W. GREENE, and T.H. MOSES, JR., Heat Flow in the Western United States: Journal of Geophysical Research, vol. 76, p. 6376-6413 (1971).